

How Density Altitude Determines Flight Characteristics

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INTRODUCTION

This unit is designed to take a set of students through the rudimentary forces that creates the lift an aircraft needs to fly through the air. The factors affecting the lifting forces are temperature, pressure, and density. The density of an air mass determines the amount of buoyant force the air mass has. The temperature determines the volume of the air mass. The pressure determines the amount of force per unit of surface area an air mass exerts on an object. The pressure of the air in a predetermined volume at a particular temperate is called the pressure altitude. When students understand how these three factors interact to create the lifting force on the airframe of an aircraft they will begin to understand the forces that govern flight. The students will then be able to predict the affect these factors cause during their interaction with the lifting force and use them to determine if a flight in any weather condition, or at any apparent density altitude, is possible.

OUTLINE

Day 1 – Introduction to Gas Properties

Demonstration 1 -- *Is It Full?*

(Asks what is capable of filling a particular volume and why, using the Inquiry Method.)

Demonstration 2 – *Is there a Set Volume?*

(Asks what changes the volume in a fixed mass, using the Inquiry Method.)

Demonstration 3 -- *Expansion Due to Pressure in a Closed System*

(Determines what causes the volume to change in a closed system, using the Discovery Method. Can be used as a laboratory experience if so desired. Followed by questions and answers used to explain results at the end of the procedure.)

Day 2 – How Temperature Affects Density Altitude

Demonstration 4 – *Absorption of Heat*

(Explains how heat can change the volume of a fixed mass of substance and therefore change the density of the system, using the Inquiry Method. Can be used as a Laboratory experience for the students.)

Demonstration 5 – *Forces in Fluids*

(Explains how substances move from areas of high pressure to those of lower pressure, using the Inquiry Method.)

Day 3 – How to Determine the Buoyant Force in the Atmosphere

Demonstration 6 – *Buoyant Force*

(Explains how Archimedes Principle can be related to the lifting forces experienced by aircraft using a simple procedure.)

Demonstration 7 – *Straw Glider*

(Illustrates Archimedes Principle in a flight application.)

Laboratory Experiment – *Experimental Gliders*

(Allows students to develop and use the ideas that have been demonstrated thus far in a practical application.)

Demonstration 8 – *Balancing Pressure*

(This illustrates the way air masses move from one temperate area to another, using the Discovery Method. This can also be assigned, as a Discovery Laboratory experience if so desired.)

Day 4 – Air Masses and Their Ability to Determine Flight Characteristics.

Demonstration 9 – *What is a Front?*

(This illustrates the way air masses move, using the Inquiry Method.)

Laboratory Experiment – *Charting Flight Characteristics*

(Using the different performance charts provided, the student will determine if a flight is possible. The student will then determine at what density altitude and temperature the flight can be safely made and over what obstacles.)

Chart A is the *Takeoff Distance Requirements* at different temperatures and pressure altitudes.

Chart B is the *Rate of Climb Requirements* at different temperatures and pressure altitudes.

Chart C is *Landing Distance Requirement* at different temperatures and pressure altitudes.

NARRATIVE

Day One: Introduction to Gas Properties

The atmosphere is composed of various gaseous atoms and molecules that are able to move independently of each other or as one apparently solid air mass composed of millions of atoms and molecules. These gaseous particles act as if they are an isolated part of the individual matter in the universe, while at the same time being part of the larger mass of air that interact and move as a single unit(s). These units of gaseous particles are what surround our planet and make up our atmosphere. The ability of these gaseous particles to form layers at different altitudes above the Earth, in the Troposphere, is a function of their density which is dependent on the temperature, volume, and number of particles present in any vertical column of an air mass.

Density is defined as the amount of mass (matter in an object) divided by its volume (amount of space that the object occupies in space). Matter with the greatest density will have the greatest mass per unit of volume. It will settle to the bottom of any vertical

column of the atmosphere. Therefore, the layer closest to the ground is the densest air. (This is the layer of the atmosphere where life is found on the planet Earth.) As you rise vertically, the density of the atmosphere, or air, decreases. This characteristic of changing density in the atmosphere is a function of the pressure of the particles above pushing down on the particles below them. This pressure causes the volume to change if there is no change in temperature accompanying it. The vapor content of the water is the other factor that can affect the density of the air because it changes the amount (mixture or mixture of gases) of gaseous matter in the atmosphere at any given location.

Demonstration 1 -- Is It Full?

(This is done to demonstrate that there is always a space between atoms and molecules to place more substances. The additional amount of material changes the density of an object in a confined space.)

Place a 500-ml mason jar on a counter top on an electronic balance. (Record the weight after adding each set of objects.). **Ask the students if the jar is full.** They should say no. Remind them that it is full of air. **Ask them if you can add more things (mass) into the jar (volume).** They will either say yes or no. Tell them that you can. Add large marbles until the jar is full of large marbles. **Ask if it is full now.** They should say yes. Then add small marbles to the jar. **Ask the question again.** They should be becoming skeptical by now. Then add BBs to the jar. **Ask again.** Then add sand to the jar. **Ask again.** Then add water to the jar **Ask again.** Then add alcohol to the jar. **Ask again.** Then pass gaseous carbon dioxide into the container. The students should be made aware that a volume is never completely filled. That the total mass changes with the addition of each substance and there is no end to the new substances that can be added. There is always another smaller compound that can fit between the larger items already in the container. (The smaller marbles fit between the larger ones, the BBs between the marbles, the sand between the marbles and BBs, the water between the solids, the Alcohol between the water molecules, and The Carbon Dioxide is able to fit between the solid and liquid molecules; regardless of the size of an object there is always another object that will fit between the last one added to the container. The ability to accommodate another particle into a fixed volume helps us to understand and determine the way density changes in any fixed volume of space.)

This demonstration illustrates that the density of an object is comparable to the ratio of the mass in that volume, to a comparable substance in the same volume. The atmosphere is composed of many different gases and substances, which change constantly with a change in temperature or pressure. The ability of the atmosphere to have density tells us that it must have a mass and a volume. This ability of the atmosphere to have mass per unit of volume tells me it can exert a force on another object when it encounters it. This force is experienced as a push or a pull on the object itself. This push or pull can be felt as wind or as lift, two topics we will explore further.

Volume is the amount of space an object occupies. The volume is dependent upon the temperature and pressure exerted on the container. The greater the temperature, the greater the movement of the atoms within the container: the greater the number of collisions between these particles and the container itself. The greater the number of collisions within the container the greater will be the pushing force against the container. This pushing force is felt as pressure against the sides of the container. Pressure is defined as the amount of push per area of volume. Therefore the greater the number of collisions against the container, the greater the amount of force applied to the container and the greater will be the pressure against the container. If the pressure in the container is great enough to exceed the force of attraction between the atoms of the container, then the container will rupture and the atoms contained within will escape from the container. Therefore the rate of movement of the particles within the container is critical. The greater the temperature in or on the container, the greater the movement of the atoms, and by default the pressure inside the container. The opposite effect is true with a decrease in temperature. The atmosphere is a container that is held together by gravity. The greater the number of atoms or particles in the air, the greater will be the pull of gravity upon them. The greater the attraction between the particles the greater the number of collisions between the atoms contained within the container and the pressure in the container. This affect of temperature and pressure explains the reason air can lift a plane. The greater the number of particles in the air, the greater the density of the air within its volume and the greater the pressure upon any object contained within that volume. This increase in density and pressure explains the way that the atmosphere (atoms) is able to move an object within its space.

Demonstration 2 -- Is there a set volume?

(Shows the affect of temperature on the volume of a sealed container)

Blow up a balloon. Tie off the end. **Ask the students if the balloon has a fixed volume?** They should answer that it does. (In fact it does not.) Place the balloon in an ice bath and leave it for five minutes. (You could place it in the freezer if you have.) **Ask the students if the balloon lost any volume in the ice bath?** They should say yes. Now place the balloon in a boiling water bath for five minutes. **Ask if the balloon has expanded.** They should say yes. **Ask the students if the number of atoms in the balloon has changed.** This should stump them. Half will say yes and half will say no. (Actually the number of atoms is unaffected by this change in volume.) The temperature change in the balloon proves Charles' law, that the change in temperature is directly proportional to the change in the volume of an object if the pressure is constant. The number of atoms in the sample follows the Ideal Gas Law, which states that the number of particles is constant if no change in the number of particles is made. The ability to show that temperature and volume is independent of the number of particles proves the pressure in the atmosphere is also independent of the number of particles present in the air. Rather, it is the size and temperature of the particles in an air mass, or layer, that is supplying the Kinetic Energy to change the volume of the air mass.

Demonstration 3 -- Expansion due to pressure in a closed system.

(The aim of this demonstration is to help prospective and experienced science teachers illustrate the scientific laws and principles of pressure differences in containers and other similar objects by using familiar items found in the home. The question that is posed to these educators is: Why does volume change in a container related to its pressure differences in the atmosphere.)

The next demonstration illustrates how the pressure and temperature affect the way we breathe. On hot days we can barely catch our breath and on cold days our lungs feel as if they are about to explode due to the amount of cold air we are inhaling. This demonstration also indicates that an airplane must take in air to burn fuel in its cylinders and uses the same air to support itself in the atmosphere. The ability to change the actual volume of the atmosphere helps us to determine the correct density altitude of the atmosphere and its lifting abilities at that density altitude.

See Figure 1.

Most individuals have an idea that containers have pressure. Yet they do not understand how a container can have a different pressure depending on its volume changing under different conditions. Through life's experiences, they have learned that a plastic bag will inflate as one places one's hand in to reach for the bottom, but do not understand why. What most people do not realize is that a change in volume causes the bag to expand. Similarly, a container's pressure varies according to the volume changes it undergoes. This idea involves the principles of pressure laws, which has been studied extensively by physicists and engineers.

Materials:

One plastic cup, one approximately 8 to 12 inch piece of vinyl tubing, one tubing T- adapter, Two 7inch balloons, one giant balloon, scissors and two rubber bands.

Procedure:

1. Insert the vinyl tubing through the plastic cup, which already has a hole drilled out to receive it. Allow tubing to exit out of cup's bottom approx. 1 in. (Note: this may be a little difficult due to tight fitting)
2. Obtain the tubing T-adapter and tighten 2" balloons to horizontal ends on adapter utilizing the 2 rubber bands.
3. Insert the vertical end of the t-adapter to the vinyl tubing. Which will protrude out of the upper portion of the cup. Pull the vinyl tubing downward towards the bottom end using the 1-inch portion. Pull the tubing until adapter/balloon apparatus is setting approximately 1/3 to 1/2 up the cup. **See Figure 4.**
4. Cut the top portion of giant balloon and stretch over the top (mouth) of cup. **See Figure 4.**

5. Explain to the students the reason for the demonstration, which is to determine what happens to the pressure if the volume in the cup or balloon is changed. Ask the students to predict what will happen when the cups inner volume is decreased. Then record their predictions on the chalkboard.
6. Now push up on the giant balloon toward the inside of the cup and ask the students to observe what happens to the balloons on the adapters. Observe their reaction and ask them to think of why the action is occurring. Then, pull down on the giant balloon and again ask the students to observe and explain what is happening.
7. Another activity that can be undertaken after the demonstration is to ask students to think of other everyday items could be used as examples for discovering the pressure principles discussed today.

Questions and Answers

1. Why did the balloons deflate when the giant balloon was pushed inward?

ANSWER: As the rubber sheet moves up, the volume in the cup and the balloon decreases with the corresponding increase in pressure within the cup. This causes air to rush out of the tube, resulting in the collapse of the balloons.

2. Why did the balloons inflate when the giant balloon was pulled outward?

ANSWER: When the rubber sheet moves down, the volume increases with a corresponding decrease in pressure. Thus, the balloons inflate. **See Figure 3.**

3. What Law does this demonstration represent?

ANSWER: Boyle's Law, which states that the volume of a gas varies inversely with the pressure. If the size of a container is decreased, then the pressure inside it increases. In the following figure (1), for instance, the initial pressure is 1 atmosphere. The gas molecules striking the wall of the container create this pressure. If the piston is pushed down, the gas is concentrated in a smaller volume. This means that the same numbers of gas molecules are striking less wall space. The gauge shows that the pressure doubles as the gas is compressed to half its volume. The same number of molecules in half the space produces twice the pressure. Conversely, if the piston is raised to increase the volume, the pressure decreases. **See Figure 4.**

4. What was the demonstration a good representation of?

ANSWER: This demonstration is a good representation of the human lungs. This model (fig. 2) allows students to visualize the fundamental physical changes which take place during Breathing (Respiration). Inspiration during quiet breathing is mainly the result of contraction of the diaphragm, which moves downward in the thorax and increases the intrathoracic volume. Air enters the lungs during this phase of respiration. This breathing process is also called inhalation. The phase of respiration during which air leaves the lung is called expiration or exhalation.

See Figure 5.

5. What are other objects in our everyday lives also apply to Boyle's Law?

ANSWER: Boyle's law applies to the operation of a bicycle pump and the blowing up of a balloon. Differences in pressure force air into our lungs when we inhale and force the air out when we exhale.

Day Two: How Temperature Affects Density Altitude

This pressing of one layer upon another over a surface area is what we refer to as pressure. Pressure is defined to be the amount of matter pressing down on the surface of an object. This pressing of one air molecule upon another is what causes the layers to compress. This affect also helps create and separate the different layers of the atmosphere. Above a certain level the air's density is too small to hold enough atoms per unit of volume to support life. This occurs at about fourteen thousand feet.

The ability of the atmosphere to have density and pressure accounts for the movement of the air above the earth. When the atoms in the atmosphere are heated or cooled, the volume and pressure of the atmosphere changes. The greater the heating of the atoms, the smaller the density becomes due to the particles separating or moving apart. The cooler the temperature, the greater the density is due to the particles moving closer together.

This heating and cooling of the air causes convection currents to form and moves the air about its container both vertically and diagonally. The rising air will carry anything whose density is less than itself into the air. The cooling air will push anything less dense than itself out of the way to settle to a lower area. Thus the lift of the warm air, or the push of the cool air, creates the lift needed to move objects into the air from the face of the Earth or return them when necessary.

Demonstration 4 – Absorption of Heat

(The purpose of this demonstration is to show how heat can be absorbed and reflected. It demonstrates how temperature changes the density of the air by changing its volume.)

Heat energy, non-visible infrared rays from the sun or from other luminous sources, travels and behaves similarly to visible light. Shiny and Smooth surfaces reflect heat, dark and rough ones absorb it, and transparent ones let it go right through. In sunshine, chromed car bumpers are cooler than black ones. This is why airplanes are left as aluminum skinned bodies without paint. It helps them maintain their volume and their density in the atmosphere when they travel through different heat layers during ascent, flight, and descent. (The supersonic transports are unable to accommodate this effect and they expand and contract during actual flights. Their design engineers must take this into

account when they are doing the structural calculations for the aircraft in flight.) People in the tropics wear light-colored clothing, while Arctic explorers wear dark clothes. Houses in warm climates are white to reflect heat.

Materials:

Two identical bottles each with a narrow neck, black paint, two balloons, two empty tin cans.
Cardboard, water, two thermometers

Procedure:

Fill the two bottles with water to the same level. Paint one bottle black. Stretch the balloons, to check for their expansion. Snap a balloon on each bottle. Let the bottles stay in the sun for a while.

Procedure:

Paint one tin can black. Place the same amount of water in both. Cover both tin cans with a piece of cardboard. Pierce a hole in each and insert the thermometers. Place both cans in the sun for 15 to 20 minutes.

PRE-LAB QUESTIONS

1. Explain what you think will happen to the plain bottle with water?
2. Explain what you think will happen to the black bottle?
3. Which tin can do you think will have the highest temperature reading?

POST-LAB QUESTIONS

1. Why did the painted bottle's balloon rise?
2. Which tin can had the highest temperature? Explain.
3. What process was being used? Explain it.

EXPLANATION

The bottles:

The painted bottle will inflate the balloon more. It has expanded more because the black paint absorbs more heat energy. The shiny glass has passed through or reflected the infrared rays.

The tin cans:

The same process is true for the cans. The black can will show a higher water temperature than the shiny one.

Demonstration 5 – Forces in Fluids

(Fluids will move from areas of higher pressure to areas of lower pressure. Liquids and gases are fluids. The forces that exist in fluids are caused by the mass and motion of the particles making up the fluid.)

Thought Starter:

1. Take a can of Coke, and shake it for several seconds. Hand it to a student and ask them to please open the Coke can for you. Normally, the student will look at you and refuse.

Q: Why would you not open the can of Coke?

A: Because it will spray all over everything

Q: Why will it spray over everything?

A: Because the contents of the can is under pressure

Q: So what does that tell us about the forces in fluids?

A: That the forces in fluids will move from an area of higher pressure (the inside of the can) to an area of lower pressure (the air/fluid outside of the can)

2. Conduct an Eggciting Experiment

- a. Obtain a glass bottle with a neck slightly smaller than the size of an egg.
- b. Remove the shell from a hard-boiled egg
- c. Crumble a small piece of paper in the bottle. Carefully light a match and drop it in the bottle. (*Caution: Observe safety rules when using a lighted match.*)
- d. When the paper catches fire, carefully place the egg on top of the bottle.
- e. Q: Describe what happens to the egg when it is placed on top of the bottle.
A. The air is heated and expands in the bottle. It rushes past the egg on top of the bottle, making the egg bounce for a second.

Q. When the burning paper consumes oxygen in the bottle, what happens to the pressure inside of the bottle?

A. The pressure inside of the bottle decreases.

Q. Explain the behavior of the egg in terms of air pressure.

A. After the pressure in the bottle is decreased the pressure of the fluid outside of the bottle (the air) pushes down on the egg and pushes it into the bottle, allowing the fluid to move from an area of high pressure (outside of the bottle) to an area of low pressure (inside the bottle).

In this unit we have seen that the density, temperature and pressure of the air causes the air to move and creates a lifting forces that we use to fly planes through the air.

Day Three: How to Determine the Buoyant Force in the Atmosphere

Pressure was defined to be the amount of force per unit of area applied to a surface. The greater the force, or the smaller the area, that is pushing against an area, the greater the effect of the pressure on the object itself. For example; if the heel of a woman who weighs one hundred pounds is placed onto a high heel point with an area of one fourth inch square in total surface area, the pressure is above six thousand pounds per square inch on the pavement she walks across. If she wears a normal loafer, the pressure is applied over a greater surface area and the amount of force is reduced to six hundred pounds per square inch. Therefore the greater the surface area to make contact between the object and the force, the pressure on that area will be smaller.

Demonstration 6 -- Buoyant Force?

(This demonstration proves that a substance can support or displace the mass of another object if it is placed within it. The ability of water to support the mass of any object that has a density of less than one will be examined.)

Weigh a piece of wood 2" x 4" x 1" on an electronic balance. If you put the piece of wood into a body of water the wood will partially sink. The water will exert enough force to hold part of the weigh of the block above the surface of the water. This upward force of the water is displacing some of the downward pull of gravity on the block. This reduction in the pull of gravity can be measured by carefully adding one gram weighs to the surface of the block. Add these one-gram weights one at a time until you completely sink the wooden block. The amount of added weight measures the amount of weight that the water is compensating for when it lifts the wooden block. This amount of weight is directly proportional to the amount of weight the water is lifting. This displaced weight is called the buoyant force of the liquid or the lifting power of the water. If the upward force is 0.33 grams per cubic centimeter, then we say the buoyant force is equal to one-third the mass of an equal volume of water that the object displaces. This is true because the density of water is one gram per cubic centimeter of volume. That means that the water is displacing some of the mass of the wood. This makes the wood's density less than that of the water. Because the wood's density is less than one, the water is able to support part of the mass of the wood above the surface of the water. This amount is equal to the lifting force of the water or its buoyant force.

If we examine the demonstration, we realize that the mass is being partially supported by the underlying denser layer of water. The water could only hold up one third of the block's mass. Because it could not hold up the entire block of wood it proves that one substance (the water) can partially support another substance (the block) if the density of the second object is less than the density of the first object. In our unit we will show that the air itself holds up the largest planes ever built. This ability of the air to lift an object is a function of its density.

Demonstration 7 -- Straw Glider

(This will illustrate the buoyant force of the air. The student will determine the amount of lift the air provides to an aircraft.)

Have the students cut out a piece of paper two inches wide by eight inches long from a standard piece of notebook paper. Then have the student make a loop out of the pieces of paper by attaching the ends together. This forms two, 2-inch wide loop of paper. Have the students tape the two loops to either end of a twelve-inch long drinking straw. Now have the students propel their straw gliders into the air. **Ask them what supports the straw glider in the air.** They should say that it is the air itself that holds up their gliders. Repeat this procedure until they become tired of it. Then have them add paper clips of different sizes to their glider until they are too heavy to sail through the air.

(The straw glider floats through the air because it's density is less than the surrounding air. The ability of the air to push, or lift the glider, out of the way demonstrates that air, like the water of the previous demonstration, creates a lifting power. The paper clips, demonstrates the amount of lift required to hold up the straw glider and make it float through the air. These paper clips are canceling the amount of buoyant force the air is creating to lift the straw glider. Because the volume is so large, the amount of mass is reduced per cubic centimeter of surface. This reduction of mass per unit of volume causes the straw glider to be less dense than the density of the air around it as it moves through the air. The actual pull of gravity and the loss of lifting forces in the air will eventually cause the object to return to earth.)

Laboratory Exercise -- Experimental Gliders

The student will design and make any kind of paper plane they wish. They will bring their paper plane to the starting line and propel them forward. The plane that glides the farthest is the winner. The student's whose plane achieves the greatest distance will be the winner of the contest. The students should be allowed to repeat this activity until they achieve their best design based on their plane's flight characteristics.

The students will next attempt to build a glider that will stay in the air the longest time. They may repeat this as before or until they are happy with their results. The students will next attempt to build a glider that can carry the greatest load and still float in the air. They may make as many attempts as they wish or until the time expires.

The ability of the air to lift and support objects is critical to flight. The demonstrations and the lab have shown that the density of the air is the factor that lifts planes into the air and is a function of the amount of mass per unit of volume.

Demonstration 8 -- Balancing pressures

(The pressure in an air mass can change with a change in temperature. Aircraft often experience a hundred degree change in airframe temperature during their transitions from the ground to their flight altitudes. This apparent change in temperature on the aircraft is really the change in pressure differential inside and outside the aircraft due to the difference in temperatures in the self contained aircraft. The following demonstration is a discovery experiment and is explained following the activity.)

Today you will be observing a demonstration relating to pressure. Please answer the questions below to aid your understanding of this concept.

1. Please draw a picture of the apparatus below. Predict which way air will move when the stopcock is opened. Draw arrows on the diagram to show which direction the air will move.
2. Justify your prediction.
3. After observing the demonstration, draw a picture of what actually happens. Use arrows to indicate which direction the air moves.

See Figure 6.

Purpose:

When shown the apparatus above, most students will intuitively believe that air will flow from a larger volume to a smaller volume. In fact, the opposite occurs. This gives a vivid, memorable example of pressures attaining equilibrium called Pascal's principle. Pascal's principle states that pressure is equal throughout an incompressible fluid at equilibrium. In this case, air is an incompressible fluid because the total volume inside the balloons and pipe does not vary at any time.

By the end of the demonstration, students should understand that pressure is determined not just by the force created by, but is also affected by the area upon which the force is applied. They should then be able to use this concept to explain Pascal's principle, and give examples of when the principle is used in their daily life.

Background Information

Pressure is force per unit area. In the demonstration, the smaller balloon has a smaller area than the larger balloon but a greater internal pressure. According to Pascal's principle:

$$P_1 = P_2 \text{ or } F_1 / A_1 = F_2 / A_2$$

The force at the end of the pipe with the smaller balloon is greater than the force at the end of the pipe with the larger balloon. When the stopcock is opened, this unbalanced force causes air to move from the smaller balloon to the larger balloon. Thus, the larger balloon further inflates.

Applications of Pascal's principle are commonly seen in hydraulic systems. Hydraulic brakes on newer car models take advantage of Pascal's law to ensure safe stopping. Hydraulic lifts can be used to safely raise very heavy objects. When a student sits in a dentist's chair they also experience a hydraulic lift. In an aircraft the hydraulic system moves the controls during flight. Without the hydraulic system the pilot could not move the control surfaces against the airflow over the control surfaces. The tail of a Boeing 747 is seventy feet high by thirty feet wide. This twenty one hundred square feet of surface would never turn into a six hundred mile per hour wind created in flight if not for the hydraulic system's assist to the pilots.

Materials:

2 nine-inch balloons, ring stand, burette clamp, burette with a stopcock, and single holed rubber stopper.

Procedure:

Note: Steps 1-4 should be performed before students enter.

1. Clamp the burette to the ring stand support. Make sure the stopcock is closed.
2. Wrap one of the balloons around the rubber stopper. Make sure the hole at one end remains uncovered.
3. Remove the dropper on the burette and insert this into the hole of the stopper. Blow up the balloon 1/4 of the way full. Twist the end so that it will not deflate as you put it back onto the burette.
4. Blow up the second balloon completely several times. - It is important that it be very stretched out. After it is stretched, blow up the balloon 2/3 of the way full and attach it to the other end of the burette.
5. Hand out prediction sheet (see appendix below). Ask students to draw a picture of the system/apparatus that they see.
6. Explain to students that the two balloons are not an open system. The closed stopcock in the middle prevents the two volumes of gases from interacting and reaching equilibrium.
7. **Ask students to predict what will happen when the stopcock is opened. Will the big balloon lose its volume to the smaller balloon or will the smaller balloon give up its air to the larger balloon?** Have them draw a picture of what they believe the system will look like as well as write it in words. After giving them a minute to consider, **ask the students to raise their hands for the option they believe to be correct.** Record all predictions on the overhead or chalkboard.
8. Have students gather around the demonstration area. Release the stopcock. If they are close enough, they will hear as well as see the air move from the small balloon to the larger balloon. The observable effect takes about 20-30 seconds.
9. Give students a few minutes to write down their observations and thoughts about what occurred. **Then begin to ask questions about what happened.**
10. Squeeze the smaller balloon until it is almost empty. It will then expand just slightly to regain total equilibrium. This will demonstrate Pascal's principle, as the air will move to ensure equilibrium.

Therefore, the air moves from the smaller balloon to the larger balloon when the stopcock is opened. This allows the external pressure to push the unexpanded balloon back to its original size. The atoms within the smaller balloon enter the inflated balloon where they are able to slip between the other atoms already there, just like in the first day's first demonstration.

Questions and Answers

1. Why did the smaller balloon lose its air to the larger balloon?

ANSWER: In an incompressible fluid, Pascal's principle says that $P_1 = P_2$ at equilibrium. Initially, the pressure in the smaller balloon is greater than the pressure in the larger balloon. Since the area of the pipe is the same at each end, the region of high pressure (smaller balloon) places a larger force on the air at that end of the tube. This unbalanced force causes air to flow naturally toward regions of lower pressure (bigger balloon).

2. What is pressure?

ANSWER: This is a concept students will have an intuitive idea about, but rarely be able to explain concretely. Pressure is a force per unit area. It is measured in units of Pascal (Pa), which is a Newton per meter squared (N/m^2).

3. Why does the smaller balloon initially have a larger pressure?

ANSWER: This unusual circumstance is completely due to the latex rubber that makes the balloon. Latex's resistance to expansion reduces as it stretches and heats up. This can be seen when blowing up a balloon. The first breath that causes the balloon to expand is the most difficult. Subsequent breaths become easier. This is an analogy with which students will have had experience.

4. How do the balloons "know" when to stop changing size?

ANSWER: Air flows until the force at each end of the tube is the same per unit area. This means the pressure has been equalized. All systems move toward equilibrium. This is what causes an untied balloon to deflate. It has a higher pressure than the surrounding system.

5. If normal atmospheric is 101.3 kPa, what force does the atmosphere exert on the area of the tabletop?

ANSWER: This question will help students clarify their understanding of pressure. Students may estimate or measure the area of the tabletop. To answer this question correctly, students must know the algebraic relationship between pressure, force, and area. For example, if the tabletop area is 1.5 m squared then there will be approximately 152,000 N of force on the tabletop. Students may be surprised to learn that such a large force acts on a tabletop. This could be extended further to have them calculate their own body surface area and how much pressure acts on them everyday.

6. The television weather person often refers to regions of high and low pressure. How does this relate to winds associated with these fronts?

ANSWER: Wind is air moving from a region of high pressure to low pressure. For example, Galveston tends to be windier than Houston during the summer. This is because warm air rises, and the partial vacuum (low pressure) is filled by cooler air coming in from off the ocean. Depending on the class, this question may also be asked as the students enter to see what their knowledge of pressure is.

7. What are some common applications that you can think of for Pascal's principle?

ANSWER: A tube of toothpaste uses Pascal's principle to get the toothpaste out onto a toothbrush. When you squeeze the end of the tube, the toothpaste goes out the open end to equalize the pressure. Hydraulic lifts like those in a barber's chair or used by auto mechanics, also use Pascal's principle. The applied pressure on the smaller piston can be transferred to the larger piston.

See Figure 7.

Day 4 – Air Masses and Their Ability to Determine Flight Characteristics

The ability of the atmosphere to have a density and variables that change the density at the same time is what makes flying so much fun for those of us with a pilot's license. The ability to interpret and understand the changes that temperature and pressure has on the density of the atmosphere while we are flying helps us stay one step ahead of the weather and the undertaken. We become very adapt at reading the atmosphere as pressure density instead of simply pressure or density. We become extremely sensitive to changes in temperature.

The following demonstration shows how the density altitude is related to the temperature extremes of the different gases that mix in the various layers of the atmosphere at any given place on the earth. The ability of the different density gradients to have different temperature and different pressures makes the world of the profession pilot exciting.

Demonstration 9 -- What is a front?

When most students learn about the four states of matter and the changes in the states, many important aspects of each of the properties are usually overlooked. They are aware of the fact that liquid particles tend to flow and they take the shape of the container. They are also usually knowledgeable of the fact that solids have a definite shape and volume, and the particles in solid matter are held close together by forces between them. When it comes to a gas, it is known that gases are free to move in all directions until they are evenly distributed and gas particles are not held close together by electrical type bonds.

Although this information is known, students are usually unaware of the fact that

gases are fluids too. Perhaps it is because of their invisible nature or their lack of any self-defined boundaries that give gases such a low profile. It is certainly an eye-opener when students see a dense gas such as carbon dioxide in a confined space moving as though it were a fluid. It points out the fact that some gases, such as the gas carbon dioxide, are denser than air.

The central thrust to this demonstration is to help students observe visually that gases are in fact a form of fluid. It is also the intent to observe that denser objects tend to sink in air. The problem for the student in this demonstration is to state what the carbon dioxide is doing in the demonstration and how does it manage to stay toward the bottom of the container?

Background information on weather fronts in relation to density

During the First World War a Norwegian meteorologist named Vilhelm Bjerknes discovered that air forms are distinct masses due to their densities. Because each air form differs in its average temperature, and therefore its density, air masses do not mix. The actual boundary between the air masses is known as a front. The way fronts move is an area of mass that travels across the surface of the land and sea and has a similar temperature throughout. If the air behind the advancing front is warmer, it is called a warm front. If the air behind the advancing front is cooler, it is a cold front. Air behind warm fronts is less dense than air behind cold fronts (warm fronts have a gradient of 1 degree or less and cold fronts are 2 degrees). Cold fronts tend to move faster across the surface of land and sea than warm fronts. Cold air tends to undercut the warm air making it rise upward along the edge of the cold front. This is due to density differences. The warm air rises quickly making the warm air and cold air separate. Usually the cold front produces thick clouds and heavy rain. Warm fronts commonly produce drizzles and showers and in the winter freezing rain and snow.

See Figure 8.

Materials:

Dry ice, beaker, 150 ml of water, aquarium, long candles of different lengths, igniter

Procedure:

1. Ask students: What are examples of everyday events that you would associate with density? (List events on the board)
2. Give the definition of density.
3. Explain frontal systems in relation to density (explanation above)
4. State the question of the demonstration: How does carbon dioxide gas tend to stay at the bottom of a confined space, and in what state does the carbon dioxide appear to be in?
5. Obtain an aquarium
6. Place the candles of different lengths on one side of the aquarium.

7. Obtain a beaker with 150 ml of water.
8. Place the beaker containing 150 ml of water in the aquarium on the Opposite side of the candles.
9. Use the igniter and light each of the candles.
10. Ask the students: What is the carbon dioxide gas going to do when released in the aquarium?
11. Using a pair of thermal gloves, place a small square of dry ice in the 150 ml of water. Allow the carbon dioxide gas to fill the bottom of the tank. Taking out the lit candles at different times.
12. Explain how gases are a fluid and have students observe this by moving the carbon dioxide gas with fingers. (Students may also come to observe this themselves).
13. Observe how the carbon dioxide gas is confined within the aquarium and the fact that denser objects tend to stay at the bottom.

Questions and Answers

1. What is density?

ANSWER: Density is the mass per unit volume of a material (g/cm^3). Density describes how tightly packed a substances molecules are.

2. What is the density of air and the gas, carbon dioxide?

ANSWER: CO_2 , which is the carbon dioxide gas, has a molecular weigh of 44.0 g/mole, which makes it considerably denser than air with a molecular weight of 29.0 g/mole.

Thus, CO_2 will tend to sink in air.

3. Why did the carbon dioxide stay toward the bottom of the contained area of the aquarium?

ANSWER: The CO_2 is denser than air so it tends to sit at the bottom of the confined area.

4. How did the carbon dioxide gas maneuver when moved with fingers?

ANSWER: Because most gases are considered fluids in air, the carbon dioxide appeared to maneuver as a liquid would flow. Carbon dioxide gas stays in this state unless the room temperature is minus 78 C. At this temperature, the substance is pulled into a solid.

5. What is a weather front?

ANSWER: A long, narrow band of changing weather that marks the area where 2 different kinds of air masses meet. For example: When a cold air mass pushes a warmer air mass out of the way, we call the boundary between them a cold front.

6. Why do fronts give birth to storms?

ANSWER: Fronts create storms because the warm air is above the cold air, which is heavier, and the conditions become favorable for rain or snow.

Laboratory Experiment -- Charting Flight Characteristics

Now that we understand the affect of density, temperature, and pressure we can look at the way they affect the flight of an aircraft. If the day is warm the air is said to be thin. That is the atoms in the atmosphere tend to spread apart and lose their lifting ability because the air is less dense. If the day is cool the air is said to be thick. That is the atoms in the atmosphere tend to come together and increase their lifting ability because the air is denser. These temperature extremes are also felt when the pressure of one air mass is different from another air mass if the two air masses have the same temperature. This is due to the different number and kinds of atoms in the two different air masses.

The ability to predict and understand the affect of temperature and pressure has created the science of meteorology. A skilled meteorologist can tell pilots the forecasted weather conditions in any area of the country based on their understanding of weather maps. The meteorologist is the first line of safety for any pilot.

If a pilot carefully studies the density, temperature and pressure in an area of intended flight they can safely pass through the area. If they ignore weather warnings or fail to determine safe conditions, they can have serious accidents or fatal crashes.

The following charts are used to determine where it is safe to take off from, fly through, and land at during any flight. If the pilot follows the recommendations obtained during the weather briefing they will always have a safe flight. Using your understanding of the temperature, pressure, and density in your area, determine if a safe flight is possible using the following informational weather chart.

Using the following Takeoff Distance Chart to determine if a takeoff is possible in your area today at the current temperature? If it is possible, tell me under what conditions would it be unsafe or impossible to do?

See Figure 9.

Using the following Rate of Climb Chart to determine what rate of climb is possible in your area today and at what current temperature? If it is possible, tell me under what conditions would it be unsafe, or impossible to do so?

See Figure 10.

The student will attempt to determine if the aircraft can safely land at a destination of their choice. The student will determine the temperature and pressure altitude at that destination from the chart below. The students will then decide if the necessary landing distance needed to bring the aircraft to a complete stop at the destination is available. Then determine if the landing is possible with or without an obstacle at the end of the runway.

See Figure 11.

A brief examination of the performance charts demonstrates that the density altitude determines the flight characteristics of any aircraft. The hotter the day, the longer the take off roll, the less the weight that can be taken into the air and the longer the distance needed to stop the plane on the ground. A cold day has the opposite affect on flight characteristics. If we examine the performance charts for any given temperature or density altitude, we can determine if a flight is possible from or to that location.

The performance charts also indicate that the density altitude is the critical factor in any flight from any airfield in the world. Therefore the need to evaluate the weather conditions one is flying from, through, and to determines the smoothness of that flight.

Have the students examine the extremes of temperature and density altitude in their area to determine if a flight is possible on any given day of the year. Be sure to examine the opposite extremes of cold and hot fronts.

ANNOTATED BIBLIOGRAPHY

Jeppensen, S. Sanderson. Private Pilot Manual: 1972 Edition: Jeppensen Sanderson, Inc. 8025 E. 40th Ave., Denver, Colorado 80207, USA

This is the basic piloting manual used to qualify pilots to fly. The explanations and problems are excellent for the beginner or the seasoned pilot. It explains in simple terms the necessities of flight for any user. It details weather and the forces that relate to it in flight.

McLaughlin, C.; Thompson, M. Physical Science: 1991 Edition: Glencoe / McGraw-Hill 936 Eastwind Drive, Westerville, Ohio 43081

Basic Physical science textbook. It explains the concepts of density, pressure, and temperature very well.

Roberson, P.; Mitchell, N. Aerospace Science: The Science of Flight: 1993 Edition: Air Force Junior ROTC Maxwell Air Force Base, Alabama 36112-6106

This is the basic high school text of aviation history and simple flight characteristics. It explains weather and air mass characteristics in detail. It is an excellent source reference for any aviation information and the forces that affect flight.

APPENDIX OF ILLUSTRATIONS

Figure 1

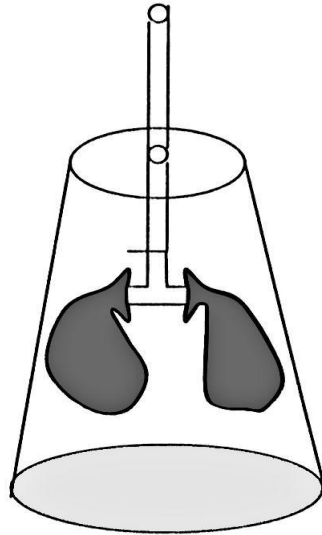


Figure 2

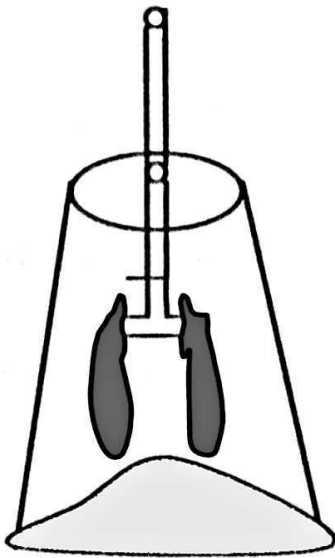


Figure 3

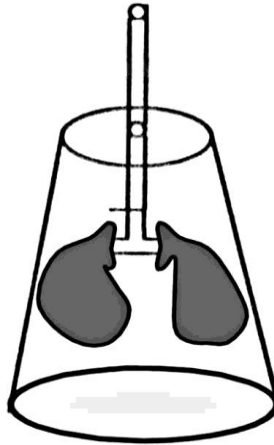


Figure 4

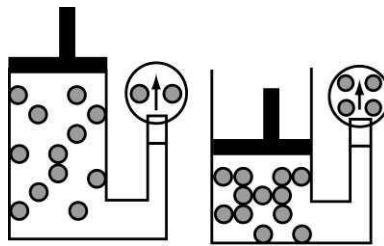


Figure 5

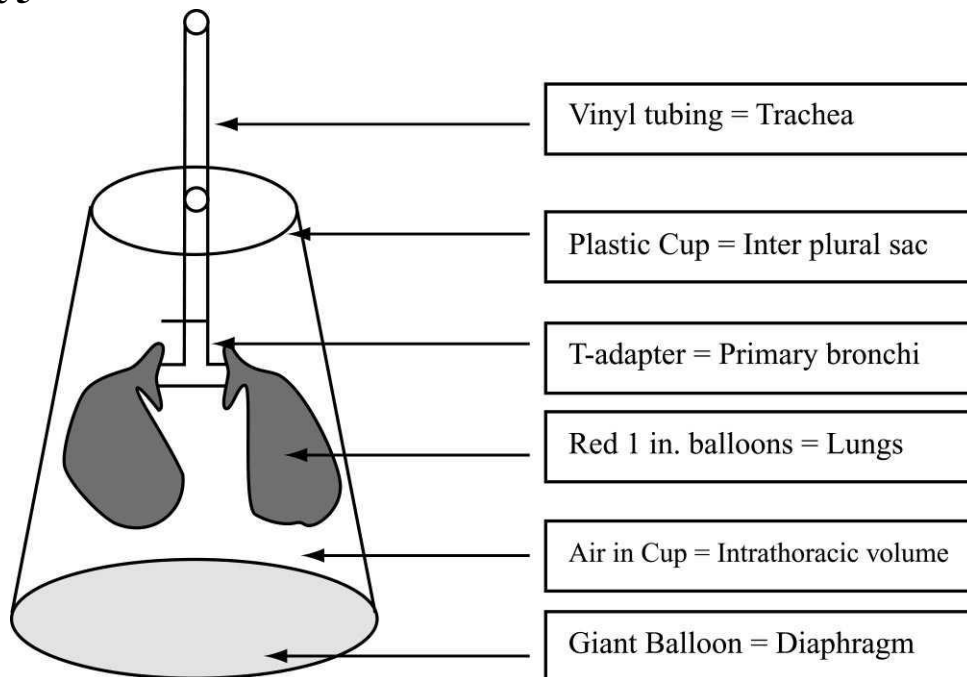


Figure 6

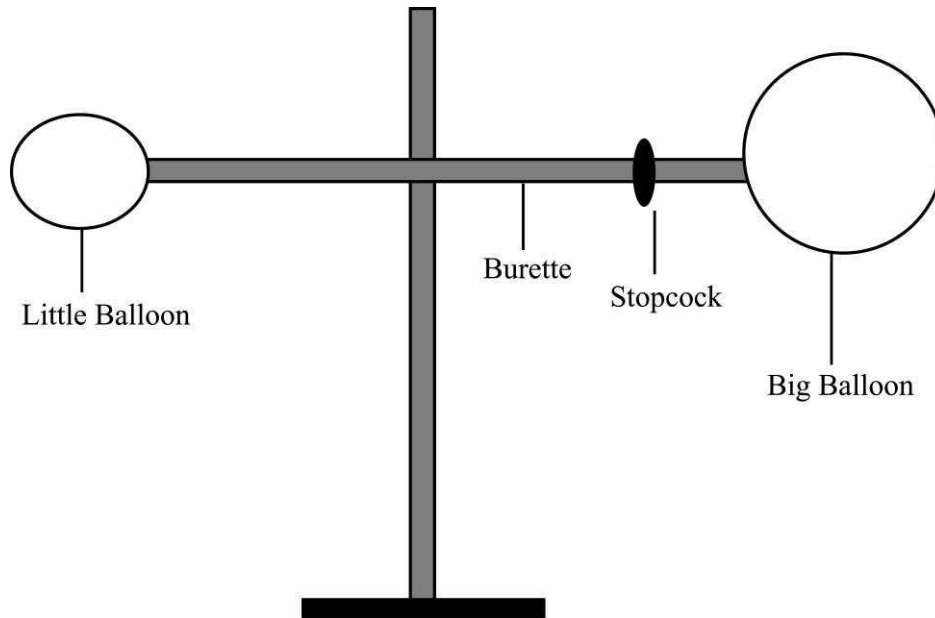


Figure 7

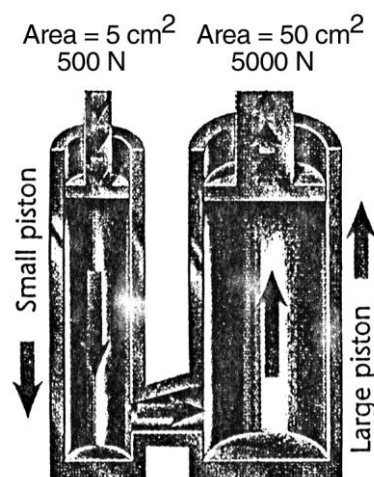


Figure 8

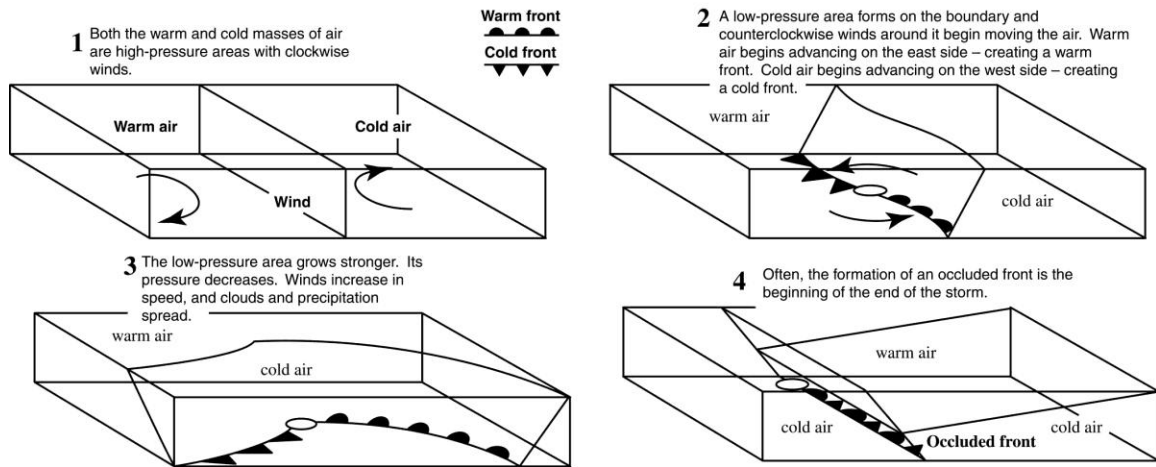


Figure 9a

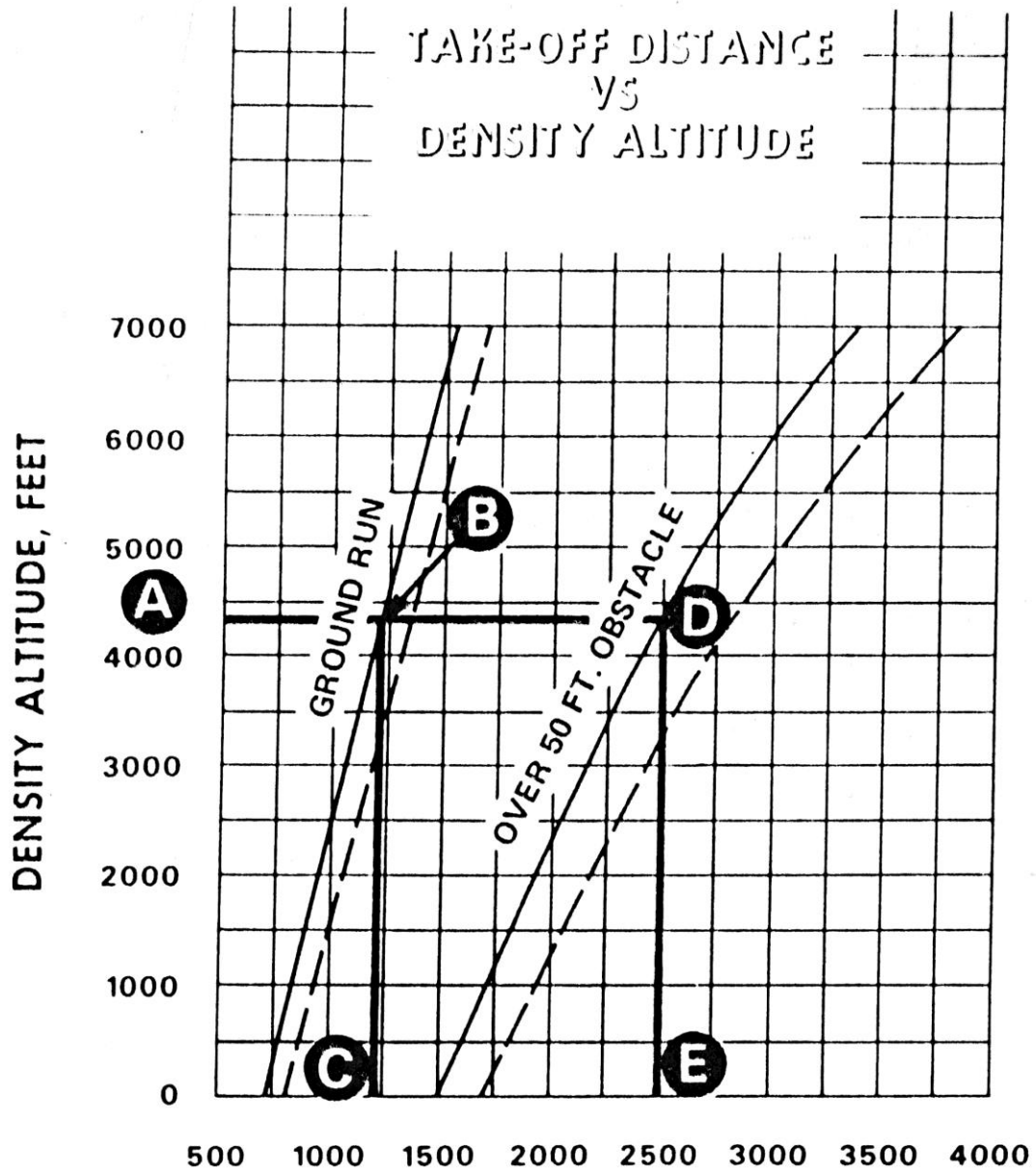


Figure 9

Pres Alt ft	0° C	0° C	10° C	10° C	20° C	20° C	30° C	30° C	40° C	40° C
	Take Off	Clear	Take Off	Clear	Take Off	Clear	Take Off	Clear	Take Off	4
	distan ce	50' obst	distan ce	50' obst	distan ce	50' obst	distan ce	50' obst	distan ce	50' obst
S.L.	655	1245	710	1335	765	1435	820	1540	880	1650
1000	720	1365	775	1465	835	1575	900	1690	970	1815
2000	790	1500	855	1615	920	1735	990	1865	1065	2005
3000	870	1650	935	1780	1010	1915	1090	2065	1170	2225
4000	955	1820	1030	1965	1115	2125	1200	2290	1290	2475
5000	1050	2015	1140	2185	1230	2360	1325	2555	1430	2770
6000	1160	2245	1255	2435	1360	3640	1465	2870	1580	3120
7000	1285	2510	1390	2730	1505	2970	1625	3240		
8000	1420	2820	1540	3080	1670	3370				

Figure 10

Pres Alt ft	-20° C	0° C	20° C	40° C
S.L.	770	710	655	595
2000	675	615	560	500
4000	580	520	465	405
6000	485	430	375	310
8000	390	335	280	215
10,000	295	240	185	
12,000	200	150		

Figure 11

Pres Alt ft	0° C	0° C	10° C	10° C	20° C	20° C	30° C	30° C	40° C	40° C
	Take Off	Clear	Take Off	Clear	Take Off	Clear	Take Off	Clear	Take Off	4
	distance	50' obst	distance	50' obst	distance	50' obst	distance	50' obst	distance	50' obst
S.L.	425	1045	440	1065	455	1110	485	1135	880	1650
1000	440	1065	455	1090	470	1135	505	1165	970	1815
2000	455	1090	470	1115	490	1165	520	1185	1065	2005
3000	470	1115	490	1140	505	1195	540	1215	1170	2225
4000	490	1140	505	1165	525	1225	560	1245	1290	2475
5000	510	1170	525	1195	545	1255	585	1285	1430	2770
6000	530	1200	545	1225	565	1285	605	1315	1580	3120
7000	550	1230	570	1260	590	1320	630	1350		
8000	570	1260	590	1290	610	1350	655	1385		